Defence and Civil Institute of Environmental Medicine

January 1984

DCIEM No. 84-C-05

Measurement of the Body Composition of Canadian Forces Male Personnel

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ABSTRACT

The purpose of this study was to evaluate the procedures described in the Health and Welfare Canada Standard Test of Fitness (STF) for determining body density and hence percent body fat from four skinfold measures. Underwater weighing (UWW) and anthropometric measures (7 skinfold thicknesses, 4 circumferences and 2 bone diameters) were performed on 110 male CF volunteers. Body density values determined by UWW were compared to values predicted from the sum of four skinfolds, using equations developed by Durnin and Womersley as outlined in the STF. In addition, multiple linear regression equations were generated from the anthropometric data to see if other combinations of variables could predict density values more accurately than STF procedures. For the total sample, body fat estimates using the STF procedures were significantly higher ($p<.05$) by 2 to 3 percent than those determined from either UWW or the regression equations.

The correlation ($r=0.82$, $p<.01$) between the UWW and the STF estimates of density for the total sample was lower than the correlation between the UWW and other anthropometric estimates of density when two or more variables were used in the multiple regression equations, ($r=0.85$ to $r=0.89$, $p<.01$). When the sample was divided into age related sub-groups, the correlation between the UWW and the STF estimates of density for the older age group was greatly reduced ($r=0.52$, $p<.05$), while the correlation between the UWW and the other anthropometric estimates of density, using one to five variables, remained high ($r=0.75$ to $r=0.95$, $p<.01$).

These data suggest that the estimation of body fat using the STF procedures may lead to overprediction for all individuals, and large errors in prediction for older individuals in the CF male population.

INTRODUCTION

The Health and Welfare Canada Standard Test of Fitness (STF) (1) includes an assessment of body composition in which body density is estimated from the sum of four skinfold thicknesses, using age-specific regression equations developed by Durnin and Womersley (2). The density value is then entered into the equation of Siri (3) to determine percent (%) body fat. Lean body weight (LBW) can be calculated from total weight and % body fat, completing the description of body composition.

Other anthropometric variables, including body and limb circumferences, bone diameters and various skinfolds, can be measured and used to construct sex and age specific regression equations for the prediction of body density. Such equations abound in the literature; however, none have been developed specifically for the Canadian Forces (CF) male population. Predicted values for body density can be compared to values determined by underwater weighing (UWW), a commonly used criterion for the validation of such equations.

The primary purpose of this study was to assess the ability of the STF procedures to predict body density and % body fat in a CF male population. The secondary purpose was to develop new equations using the optimal combinations of up to five anthropometric variables for the prediction of body density, and to compare these equations with those used in the STF procedures for their ability to provide an accurate estimation of density and hence % body fat.

METHODS

Subjects

One hundred and ten CF males, recruited from CFB Toronto and CFB London, participated in this study. They ranged in age from 17-49 years. Physical characteristics of the subjects are presented in Table 1 in the result section.

Procedure

Each subject, wearing only a lightweight bathing suit, reported individually to the testing area. Subjects were instructed to refrain from eating or smoking for at least three hours prior to the test. Anthropometric measurements, which included height, weight, seven skinfold thicknesses, four body and limb circumferences and two bone diameters, were performed on all subjects by the same observer. Underwater weighing was conducted immediately following the anthropometry, and residual lung volumes were determined the same day in a separate testing area.

Anthropometry

Most anthropometric measures were carried out according to standard procedures outlined by Behnke & Wilmore (4); exceptions to these procedures are noted. All limb circumferences, bone diameters and skinfold measurements were taken on the right side of the body. Two readings were taken at each site, and the mean value was recorded. A third measurement was taken if the first two showed a discrepancy greater than 0.4 mm for skinfolds, 0.3 cm for circumferences, or 0.2 cm for diameters, and the mean of the closest two measures was recorded. The same observer took all the anthropometric measurements.

Height and Weight

Body weight, to the nearest 0.1 kg, and standing height, to the nearest 0.5 cm, were measured. Subjects wore shorts and were barefoot.

Skinfolds

Skinfold thicknesses were measured to the nearest 0.1 mm using Harpenden calipers, with the subject standing and relaxed. The procedures outlined in the STF operational manual were used to measure the triceps, biceps, subscapula and suprailiac skinfolds. The three additional sites measured were the abdomen (horizontal fold, 2-3 cm to the right of the umbilicus), the medial thigh (longitudinal fold at the point of the thickest deposit of fat, with the leg supported and flexed at the knee), and the medial calf (vertical fold at the level of maximal circumference, with the leg supported and flexed at the knee).

Circumferences

Body and limb circumferences were measured to the nearest 0.1 cm using a cloth tape, placed horizontally or at right angles to the length of the body segment, and taking care not to compress the soft tissue. The subject stood relaxed with heels together. Sites measured were the neck, the biceps (flexed), the waist (at the level of the umbilicus), and the calf (maximum girth).

Diameters

Bone diameters were measured to the nearest 0.1 cm using a Siber Hegner spreading caliper. Care was taken to compress soft tissue and measure with as direct a contact with the bone as possible. Sites measured were the elbow and knee with the measurements taken while the subject was seated.

Densitometry

Underwater weighing was conducted in a specially designed tank with a water depth of approximately 1.5 m. A beam was constructed above the tank to hold a Chatillon 9 kg weigh scale in a position where an observer could take an accurate reading. A nylon line connected the scale to a sling-type harness.

The subject lowered himself into the tank and was instructed to squeeze out any air bubbles trapped in the hair and bathing suit. He then put on a 3.8 kg diving weight belt, which was necessary to ensure complete submersion. After listening to instructions on how to perform a forced maximal expiration underwater, and how to hang comfortably in the harness, the subject lowered himself into the water. When the observer was confident that all air had been expelled and the subject was not touching the bottom or sides of the tank, a reading was taken on the scale. This procedure was repeated ten times or until weight had stopped increasing and three similar readings (within 20 g) had been obtained. Water temperature in degrees celsius was recorded after each subject had been weighed. Most subjects improved with practice throughout the first five or six trials, and then stabilized at a fairly constant underwater weight. The average of the three best readings, rather than the highest score, was recorded as the true underwater weight. According to Katch & Katch (5), this results in a more dependable and consistent individual score, and is the statistical procedure of choice when underwater weighing is performed in a separate location from residual lung volume determinations.

Residual Volume

Residual lung volume was determined by the single breath nitrogen washout technique, using a Hewlett-Packard Pulmonary Function System (47804S) and standard test criteria (6). The subject was in a standing position for all tests.

Calculation of Derived Values

Density, percent body fat and lean body weight were calculated from the raw data collected for each subject as shown below.

Body Density

Body density was computed from the following formulae:

$$\text{Density (gm/cc)} = Wa/((Wa-Ww/Dw)-(RV+ 0.1))$$

Where

Wa = weight in air (kg)
Ww = weight in water (kg)
Dw = density of water corrected for temperature
RV = residual lung volume (1), with 0.1 l added to allow for gas trapped in the gastrointestinal tract

Percent Body Fat

Percent body fat from underwater weighing (%BF) was calculated using the formula of Siri (3):

$$BF\ (\%) = (4.95/Density - 4.5) \times 100$$

Lean Body Weight

Lean body weight (LBW) was calculated from body weight and percent body fat using the following formula:

$$LBW\ (kg) = Wa - (Wa \times \%BF)$$

The Standard Test of Fitness Equations

The equations to determine density from skinfolds adopted by the STF were developed by Durnin and Womersley (2). Equations particular to each subject's sex and age group were used and are as follows:

Equations for male subjects:

Aged 17-29

$$Density = 1.1631 - 0\ .0632.\ \log_{10}(\text{sum of four skinfolds})$$

Aged 30-39

$$Density = 1.1422 - .0544.\ \log_{10}(\text{sum of four skinfolds})$$

Aged 40-49

$$Density = 1.1620 - .07.\ \log_{10}(\text{sum of four skinfolds})$$

where the sum of four skinfolds is the sum of skinfold thicknesses taken at the biceps, triceps, subscapular and suprailiac sites. This estimate of body density was transformed to percent body fat using the equation of Siri (3), as previously described.

Statistical Treatment of Data

Subjects were considered as a total group, and as three sub-groups based on age. Means and standard deviations were calculated for all anthropometric measures. A paired t-test was used to determine the difference between means.(7) For each group, a

stepwise multiple linear regression analysis was used to produce the optimum combinations of 1, 2, 3, 4 and 5 variables for the prediction of body density. The multiple correlation coefficient (r) associated with each combination indicated which measures best predicted density as determined by UWW.

RESULTS AND DISCUSSION

The STF Assessment of Body Composition

The physical characteristics of the subjects are presented in Table 1.

Table 1: Physical Characteristics of the Subjects (mean ± S.D.)

Parameter	All Ages (n=110)	17-29 (n=71)	30-39 (n=24)	40-49 (n=15)
Age (yrs)	27±9	22±3	33±2	44±3
Height (cm)	174±6	174±6	173±5	178±7
Weight (kg)	76±11	74±9	76±5	86±14

Table 2 presents a summary of the mean values for body density, %BF and LBW for all groups. Both body weight (Table 1) and %BF (Table 2) are higher in the older age groups, while density is reduced and LBW shows little change. This indicates that weight gained with age is a result of increased body fat, rather than a gain in lean body mass.

Table 2: Body composition determined from underwater weighing and STF procedures (mean ± S.D.)

	All Ages (n=110)	17 - 29 (n=71)	30 - 39 (n=24)	40 - 49 (n=15)
Density (g/cc)*	1.062±.017	1.068±.014	1.057±.017	1.042±.014
Body Fat (%)*	16.2±7.7	13.7±6.1	18.2±7.7	25.2±6.3
Body Fat (%)**	18.2±6.0	15.6±4.1	21.3±3.9	27.1±5.5
LBW(kg)*	63.0±8.8	63.4±6.1	62.0±7.4	63.0±7.9

* determined from underwater weighing
** determined from STF skinfold procedures
(Body fat determined from skinfolds significantly different from body fat determined by UWW, $p<.05$).

These data also indicate that values for %BF determined from the STF skinfold procedures are 2 to 3 percent greater than %BF determined by UWW, with the greatest difference occurring in the 30 - 39 year old group.

Table 3 presents the correlation coefficients for both body density and percent body fat as determined by the STF techniques and UWW. These figures indicate that for the total group, a relatively high correlation ($r=0.82$, $p < .01$) exists between these values. However, the relationship is much weaker for the oldest group ($r=0.52$, $p<.05$) when considered separately.

Table 3: Multiple correlation coefficients for density and percent body fat as determined by the STF technique and by underwater weighing

	All ages (n=110)	17-29 (n=71)	30-39 (n=24)	40-49 (n=15)
Body Density	0.82	0.78	0.86	0.52
Percent Body Fat	0.82	0.78	0.86	0.53
	(p<.01)	(p<.01)	(p<.01)	(p<.05)

The poor correlation for the oldest age group is shown in Figure 1 where the scatter for older individuals is much greater than for those in the two younger groups. This suggests that determining percent body fat from skinfold measures for older individuals may lead to errors larger than the two percent difference indicated by the mean values in Table 2.

Other Anthropometric Assessments of Body Composition

Table 4 shows the mean values for the seven skinfolds, four circumferences and two diameters, for the total group and for the three age sub-groups. Although all measurements appear to increase with age, the subscapular, suprailiac and abdominal skinfold thicknesses and the abdominal circumference show the most marked increases. This suggests that fat is being deposited to the greatest extent on the trunk of the body.

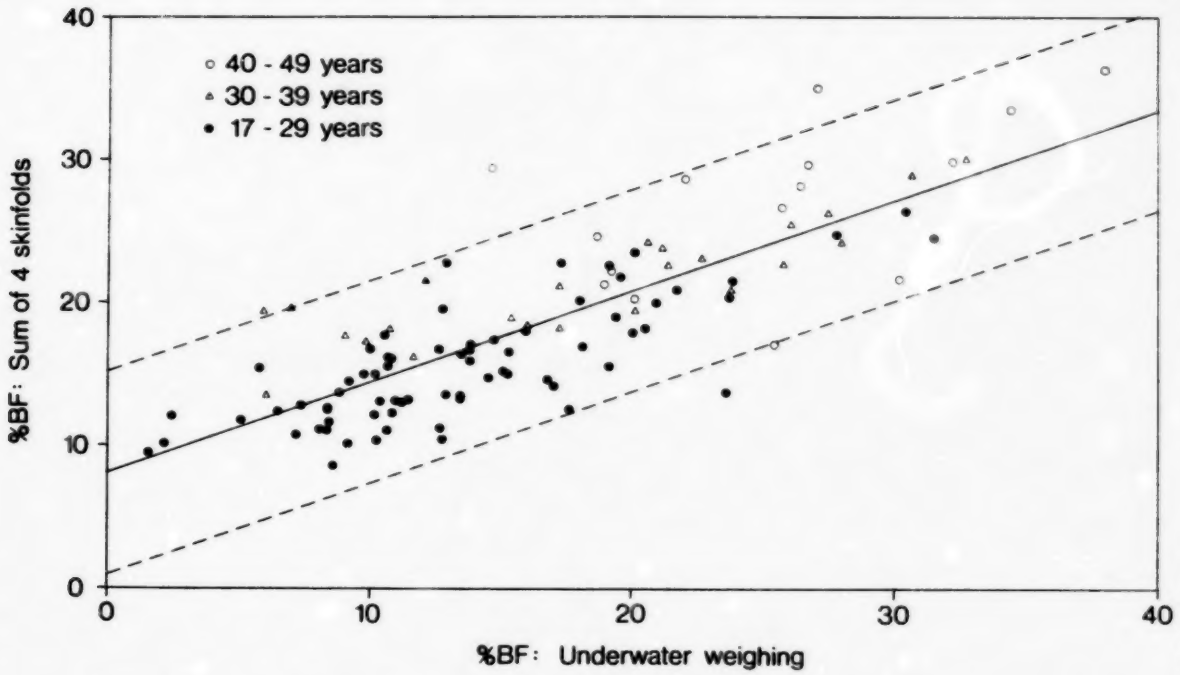

Figure 1. Comparison of Percent Body Fat determined from underwater weighing and predicted from the sum of four skinfold measures (n=110 CF male personnel). Dotted lines are 95% confidence interval.

Table 4: Values for skinfold thicknesses, limb circumferences and bone diameters (mean ± S.D.)

Variable	Abbreviation	All ages (n=110)	17-29 (n=71)	30-39 (n=24)	40-49 (n=15)
Skinfolds (mm)					
biceps	bi	5 ± 2	5 ± 2	6 ± 3	7 ± 3
triceps	tri	10 ± 4	10 ± 4	12 ± 4	13 ± 4
subscapula	sub	14 ± 7	12 ± 4	15 ± 7	20 ± 9
suprailiac	sup	17 ± 9	14 ± 7	20 ± 9	25 ± 11
abdomen	ab	19 ± 10	15 ± 8	23 ± 9	29 ± 9
thigh	thi	11 ± 5	10 ± 4	11 ± 6	15 ± 7
calf	ca	9 ± 4	9 ± 3	9 ± 4	10 ± 3
Circumferences (cm)					
biceps	bicir	33 ± 3	33 ± 2	34 ± 3	35 ± 3
calf	cacir	38 ± 3	37 ± 2	38 ± 3	40 ± 3
neck	nkcir	38 ± 2	37 ± 2	38 ± 2	39 ± 3
abdomen	abcir	85 ± 9	82 ± 7	86 ± 9	95 ± 10
Diameters (cm)					
elbow	elbdia	7.2±.4	7.0±.3	7.3±.5	7.6±.3
knee	kndia	9.8±.5	9.6±.4	10.0±.4	10.2±.6

Table 5 shows the multiple correlation coefficients (r) and the standard errors of the estimate (SEE) for the prediction of body density using one or combinations of up to five anthropometric variables for the total group and the three age sub-groups. These data show that the groups differ in the anthropometric variable, or combination of variables, that give the best prediction of body density. Measurement of a single variable, thigh skinfold thickness in the case of the sub-groups and abdominal circumference for the combined group, provide a reasonably good prediction of body density ($r=0.75$ to 0.83, $p<.01$). As more variables are added, r and SEE increase and decrease, respectively, reflecting the increasing accuracy of prediction. However, the use of more than three variables in the regression equation does not produce an increase in the accuracy of prediction except in the older age group, for which the use of four variables increases r from 0.85 to 0.93.

If the suggested combinations of three variables are used for the total population and each of the age sub-groups, the following equations could be used for determining more accurate estimates of body density and hence body fat.

All Ages:
Density (g/cc) = 1.1274 - 0.0014107 (abcir) - 0.0015005 (tri) + 0.0018581 (nkcir).

Age 17 - 29:
Density (g/cc) = 1.1326 - 0.0016371 (ca) - 0.0005342 (ab) - 0.0005056 (abcir).

Age 30 - 39:
Density (g/cc) = 1.0276 - 0.0018930 (thi) - 0.0011115 (ab) + 0.0020391 (cacir).

Age 40 - 49:
Density (g/cc) = 1.1370 - 0.0026155 (thi) - 0.0017705 (age) + 0.0008523 (sup).

Table 5: Multiple Correlation Coefficients for the Prediction of Body Density* from Anthropometric Variables

Group	Independent Variables	r	SEE (g/cc)	
all ages	abcir,ab,age,ca,cacir	0.89	0.0081	p<.01
(n=110)	abcir,tri,nkcir,ab	0.89	0.0085	"
	abcir,tri,nkcir	0.88	0.0087	"
	abcir,tri	0.85	0.0092	"
	abcir	0.81	0.0103	"
17-29	ca,ab,thi,eldia,abcir	0.87	0.0073	p<.01
(n=71)	ca,ab,thi,eldia	0.86	0.0073	"
	ca,ab,abcir	0.86	0.0075	"
	ca,ab	0.84	0.0076	"
	thi	0.77	0.0090	"
30-39	ht,abcir,bicir,tri,sup	0.94	0.0067	p<.01
(n=24)	thi,ht,abcir,bicir	0.93	0.0071	"
	thi,ab,cacir	0.90	0.0084	"
	thi,ab	0.87	0.0094	"
	thi	0.83	0.0103	"
40-49	thi,age,sup,bicir,abcir	0.95	0.0055	p<.01
(n=15)	thi,age,sup,bicir	0.93	0.0060	"
	thi,age,sup	0.85	0.0084	"
	thi, age	0.80	0.0092	"
	thi	0.75	0.0097	"

* Density as determined from underwater weighing
(p<.05 for all r's)

STF vs Other Anthropometric Predictors of Body Composition

The STF method of predicting body density from four skinfolds produced correlations ranging from 0.52 to 0.86 (Table 3). When the suggested optimal combinations of three anthropometric variables were used to predict density specific for this sample and its sub-groups, the correlations ranged from 0.85 to 0.90 (Table 5). If the optimal combinations of only two variables were used, correlations ranged from 0.80 to 0.87. Thus, using only two measures, a better prediction of body density could be produced than by using the STF method. Only in the middle age group (30-39 years) does the STF method compare favourably with predictions using the optimal combinations of variables. Correlation results using the STF method for the older age group were especially poor (r=0.52); using only one variable from the other anthropometric measures gave a better estimate of density for this group (r=0.75). The small sample size (n=15) may be the main reason for the poor results obtained by the STF method.

CONCLUSIONS

1. Body densities estimated from four skinfold measurements according to the STF & UWW procedures correlate well with values determined by underwater weighing for the young and middle age groups (r=0.78 and 0.86, respectively). The relatively poor correlation for subjects aged 40-49 years (r=0.52) may be due to the small sample size (n=15); this question would be resolved by collecting additional data.

2. The estimates of body fat from the STF procedures tend to overestimate % body fat determined from underwater weighing by 2 - 3 percent.

3. Various anthropometric variables, singly or in combination, were compared for their ability to predict body density as determined by underwater weighing. Correlational analysis indicated that the best single variable, or combination of variables, differed among age groups. It was also evident that including more than three anthropometric variables in the regression equation did not appreciably increase the accuracy of predicting density or % body fat.

4. For the sample population, the age-specific equations that were developed gave better estimates of body density and % body fat than did the equations used in the STF procedures. However, because of the small numbers in the middle and upper age groups, it is possible that the equations developed for the estimation of body density in these groups apply only to the samples tested.

RECOMMENDATIONS

The number of subjects on which the equations to predict body fat are based, particularly in the middle and older age groups, is relatively small. It is therefore recommended that future studies are directed to increase the subject population and to attempt to cross-validate these equations.

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